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TECHNICAL REPORT BRL-TR-3356

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FAE BOMBING FOR MINEFIELD BREACHING

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JUNE 1992

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| 13. ABSTRACT (Maximum 200 words) Historically, bombing has not been used or extensively tested for minefield breaching. This report predicts that bombing results should be excellent even with small numbers of sorties. Fuel-air explosives (FAE), which are notably effective against pressure-fuzed mines, were the notional ordnance. For a single FAE bomb probability of one-half of making a 30-meter breach, four Harrier jets with seven CBU72 bombs each can reduce a 210-meter path through a standard minefield from 1,000 mines/km to at most 330 mines/km with 99% probability. This decreased path density provides a tank 62% chance of crossing the minefield path without hitting a mine; whereas, without the FAE bombing, a tank trying to bull through is only 25% certain of crossing safely. Killing all mines in the path is possible (82% chance) with the four jet strike. The analysis can be applied to other bombs and minefields. | | | | |
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TABLE OF CONTENTS

| | <u>Page</u> |
|---|-------------|
| LIST OF FIGURES | v |
| LIST OF TABLES | v |
| ACKNOWLEDGMENT | vii |
| 1. INTRODUCTION | 1 |
| 1.1 Purpose | 1 |
| 1.2 Background | 1 |
| 1.3 Tangible Problem | 3 |
| 2. NUMBER OF SORTIES: UNIFORM MINEFIELD | 4 |
| 2.1 Single Sortie | 4 |
| 2.2 Multiple Sorties | 7 |
| 3. NUMBER OF SORTIES: STANDARD MINEFIELD | 9 |
| 3.1 Definition | 9 |
| 3.2 Number of Sorties | 13 |
| 4. EXPECTED PATH DENSITY AFTER FAE BOMBING | 14 |
| 5. PROBABILITY OF GETTING THROUGH | 16 |
| 6. PARTIAL CLEARANCE AND BULLING THROUGH | 18 |
| 7. DERIVATION OF MULTIPLE SORTIES PROBABILITY | 20 |
| 8. CONSIDERATIONS | 21 |
| 9. SUMMARY | 22 |
| 10. REFERENCES | 25 |
| APPENDIX A: EXACT AND CUMULATIVE PROBABILITIES OF BREACHING A UNIFORM MINEFIELD | 27 |
| APPENDIX B: EXACT AND CUMULATIVE PROBABILITIES OF BREACHING A STANDARD MINEFIELD | 45 |
| DISTRIBUTION LIST | 59 |

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LIST OF FIGURES

| <u>Figure</u> | <u>Page</u> |
|--|-------------|
| 1. FAE Bombing | 2 |
| 2. Uniform (Nontactical) Minefield | 5 |
| 3. Layout of Standard Minefield | 10 |
| 4. Mine Strips Across Bombed Stretches | 12 |
| 5. Probability of Tanks Hitting Mines | 17 |

LIST OF TABLES

| <u>Table</u> | <u>Page</u> |
|--|-------------|
| 1. Exact Probability: One Sortie, Uniform Minefield | 6 |
| 2. Least Path Cleared: One Sortie, Uniform Minefield | 7 |
| 3. Least Path Cleared: Multiple Sorties, Uniform Minefield | 8 |
| 4. Number of Sorties to Clear at Least X% of Mines With at Least γ % Probability: Uniform Minefield | 9 |
| 5. Number of Sorties to Clear at Least X% of Mines With at Least γ % Probability: Standard Minefield | 13 |
| 6. Expected Path Density After FAE Bombing | 15 |
| 7. Probability of a Tank Getting Through the Breach Path | 16 |
| 8. Probability of a Tank Getting Through the Breach Path (With Less Effective Bombs) | 19 |

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1. INTRODUCTION

1.1 Purpose. This report draws out the idea rendered in Figure 1, that a minefield can be breached by bombing from husbanded sorties. A surer idea, that abounding bombing will breach a minefield, was proven by Leonard (1944), but such may never have been done in war. The Engineer Board (1945) used surface burst fuzing because bombs could not be reliably fuzed (then) for low air bursts, which would have given the largest clearance radius. Large, delay-fuzed bombs made impassable obstacles. The present variation has large radius, does not crater, and, as then, no new expensive project is needed to apply the idea—planes exist, ordnance exists. Pilot training and minefield marking are still needed.

Breaching is a combat operation of making a safe lane for armored vehicles to go through a minefield; clearing is an uncontested operation of removing or destroying all the mines in the field. With a key but unknown measure, the single success in a set distance, and with the method of this report any type of bomb, rocket, mortar, or shell could be analyzed for breaching usefulness.

This report provides the probability of breaching a minefield with drops of fuel-air explosive (FAE) bombs, when each bomb has some probability of killing all mines in a 30-meter stretch. Two minefield patterns are examined: a uniform pattern consisting of mines hidden throughout the field and a standard tactical pattern consisting of three separated strips of mines blocking the field. The probable success of one plane in bombing a path is found to be low, but a small number of sorties will raise the probability greatly. All mines in the path can be killed, even with husbanded sorties. Even partial success in killing mines will create a usable path. Overall, the report is conscious of operations planning and sortie use.

1.2 Background. Numerous static tests, one expeditious bombing test, and rocket tests of fuel-air explosive warheads show that FAE is effective against pressure-fuzed mines, the most common type of mine (Dennis 1973). Army intentions were to apply FAE. That it did not happen is due partly to cost of land systems FAE and to the appearance of blast-resistant

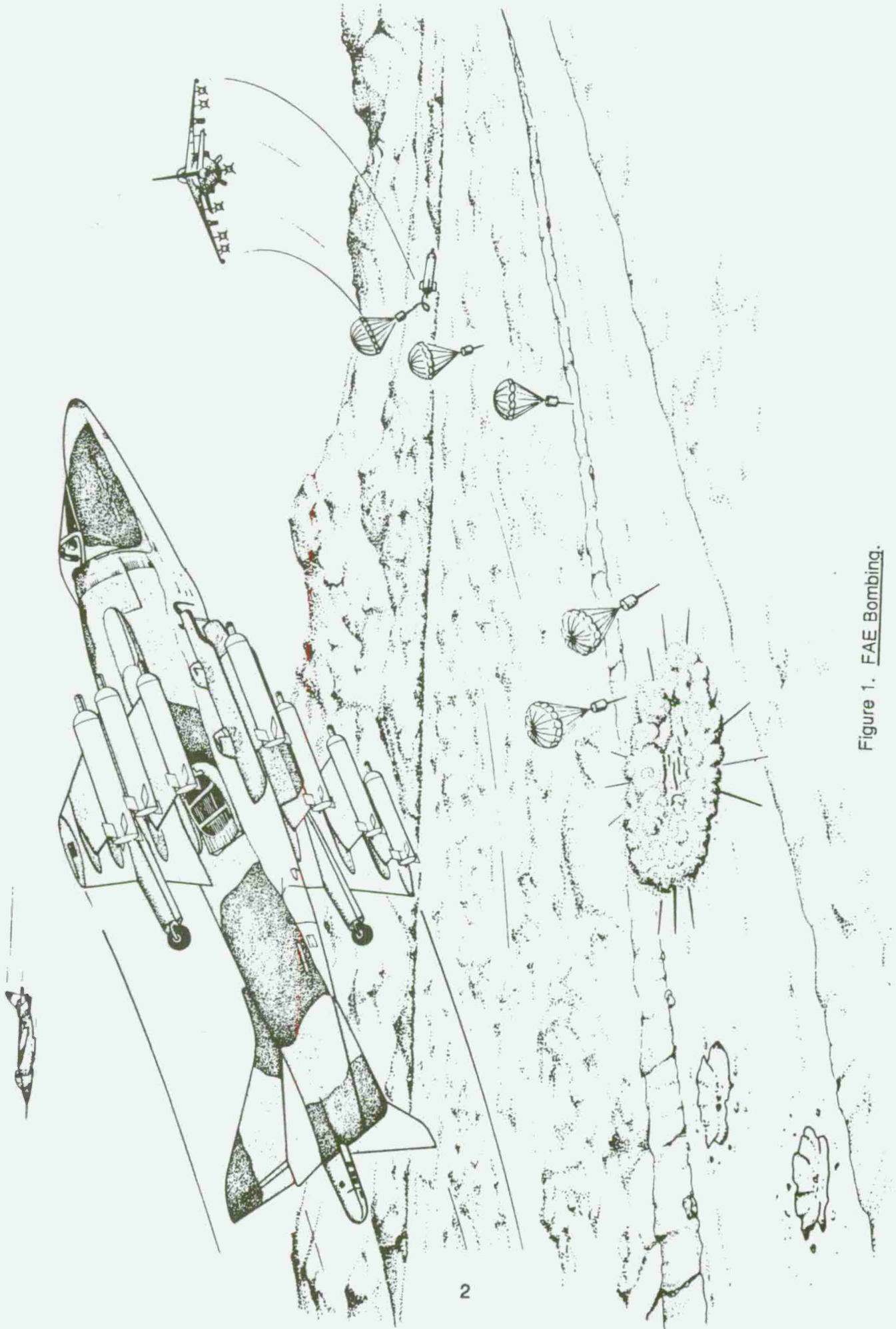


Figure 1. FAE Bombing.

mines. Large aerial bombs* were stopped in advanced development by the Navy because of unadaptable (flammable liquid storage) requirements on aircraft carriers and because FAE funding was transferred to unrelated overcost Navy projects.

The only type of FAE bomb that remains in inventory is a triple-warhead, cluster munition. Actually, multiple warheads, falling nearly in line, and not large unitary FAE bombs are ideal for path clearing. The path made by large bombs would be too wide and too short. The jet-rated Cluster Bomb Unit is the CBU72; its near twin is the CBU55, intended for low speed drops. The CBU72 is certified for use on the AV8B Harrier II, A6 Intruder, and F18 Hornet. The ballistic table of the CBU72 is installed in the planes' bombing computers, except in the Hornet's. For minefield breaching, a full bomb load would have to be ripple-dropped under computer control.

Although not optimized or designed for minefield breaching, the CBU55 was dropped on minefields from helicopters and its effectiveness rated primarily against a requirement that it be able to create a 30-m breach (Dennis, Comeyne, and Millman 1973). FAE kills all susceptible mines under the cloud, which is 13 m in diameter for a warhead in the CBU55 bomb, and there are three warheads in the bomb. So, the breach requirement was not a stiff one. The probability of success was variously rated so that

$$0.1 \text{ [TECOM Evaluator]} < p(30\text{-m}) < 0.8 \text{ [MERADCOM Tester]}.$$

This uselessly wide range on $p(30\text{-m})$ was caused by analysts' decisions on which bomb drops to include or exclude. Several warheads never landed in the minefield—primarily because of high altitude release, primitive sighting system, and inexperience in bombing from Army pilots. The authors feel that the true p is at the higher end of the range, but the present calculations use a spread of p , and each p has a consequent result on the number of sorties.

1.3 Tangible Problem. For tangible results, the estimated capabilities of a CBU72 FAE bomb and AV8B Harrier aircraft are used in the calculation. The FAE bomb has been given

* Aerial bombs never were intended for mine field breaching. Simple drops for destroying mines in assault helicopter landing zones were contemplated.

capability, not certainty, of mine killing over 30-m stretches. In the probability value $p(30\text{-m})$, we allow for all the influences that degrade the best FAE performance, which is seen in static canister tests (Weaver 1973) and for which FAE has sure-kill for some distance D . All compounding deleterious effects (e.g., accuracy, reliability, terminal effects) are subsumed into the single number. The method rejects studying separate effects and then mathematically joining them in a cascade to get a final system probability. The method of just picking p is a fell-swoop method which dismisses the piecemeal, engineering approach. The probability value of a single bomb success can remain arguable, even with test results, since tests usually encounter experimental problems with untried equipment. Lacking precise data, several probability values are run through the analysis. This report favors $p(30\text{-m}) = 0.50$, but values of 0.15, 0.30, and 0.70 are given for comparison and to find sensitivity on sortie number.

The Harrier can carry seven bombs singly racked and has the proper bombing computer. The longest breach that can be made by the Harrier is then 210 m long (7 x 30-m stretches). Without the minefield pattern, how many stretches are cleared is an intermediate answer which does not answer how many mines are killed. The proportion of stretches cleared in the lane is not the same as the proportion of mines killed in the lane except when the mines are uniformly distributed in all stretches. Figure 2 is a pattern that puts a mine in each 30-m stretch and gives a minefield density of 1,000 mines/km. The pattern is tactically unrealistic, but it is analyzed because it is conceptually easy; it is like some used on large scale clearance tests, and it is a limiting case of a (tactical) strip minefield to come. It will be shown that the bombing results are not greatly different over a uniform or strip minefield pattern.

2. NUMBER OF SORTIES: UNIFORM MINEFIELD

2.1 Single Sortie. Refer to Figure 2, which shows a path bombed through a pattern of a mine in every one of seven 30-m stretches. The breach width of 7 m is enough to give a one-way, one-lane path for tanks. The problem is to calculate the probabilities of no stretches cleared, one stretch cleared, ..., all seven cleared. We say that clearing by bombing can be modelled if the following conditions apply: the bomb drops are independent events, the same probability of success applies to each and every bomb, and there are only two outcomes in a

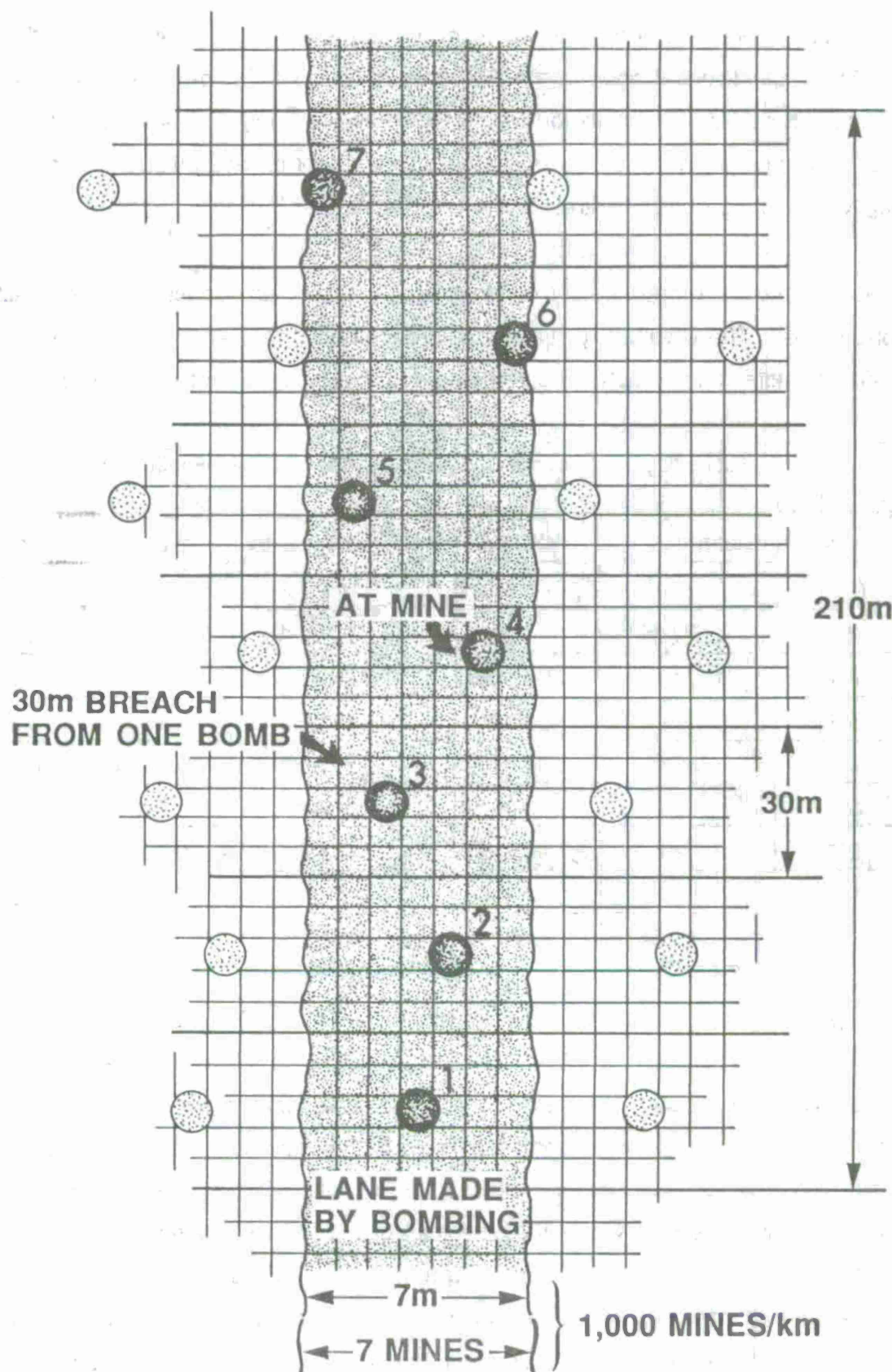


Figure 2. Uniform (Nontactical) Minefield.

stretch—clearing all mines or not clearing all mines in that stretch. (Partial clearing does not count.) These conditions define a random process for which the binomial distribution function supplies the probability of success for one sortie. Identification of the correct distribution leads to a look-up of probability of number of stretches cleared out of seven (i.e., $r/7$) and the probability of clearing r or more stretches by one sortie.

Table 1 shows the probability of clearing exactly (no more and no less than) r stretches from one Harrier. The CBU72 is given four different probabilities, values of $p(30\text{-m})$, of clearing a single 30-m stretch. The entries are from a binomial probability table.

Table 1. Exact Probability: One Sortie, Uniform Minefield

| Proportion Cleared* | | Probability of Clearing Exactly r of Seven Stretches | | | |
|---------------------|-----|--|----------|----------|----------|
| $(r/7)$ | (%) | $p(30\text{-m}) = 0.15$ | $= 0.30$ | $= 0.50$ | $= 0.70$ |
| 7/7 | 100 | 0.0000 | 0.0002 | 0.0078 | 0.0824 |
| 6/7 | 86 | 0.0001 | 0.0036 | 0.0547 | 0.2471 |
| 5/7 | 71 | 0.0012 | 0.0250 | 0.1641 | 0.3177 |
| 4/7 | 57 | 0.0109 | 0.0972 | 0.2734 | 0.2269 |
| 3/7 | 43 | 0.0617 | 0.2269 | 0.2734 | 0.0972 |
| 2/7 | 29 | 0.2097 | 0.3177 | 0.1641 | 0.0250 |
| 1/7 | 14 | 0.3960 | 0.2471 | 0.0547 | 0.0036 |
| 0/7 | 0 | 0.3206 | 0.0824 | 0.0078 | 0.0002 |

* The proportion cleared is based on 210 m with seven CBU72 FAE bombs from one Harrier.

The probability of clearing r or more stretches with one sortie is given in Table 2. The entries are partial sums of the entries in Table 1. An equivalent meaning of clearing " r or more stretches" is clearing "at least r stretches." So at least 5/7 stretches cleared by 0.50 effective bombs with probability of 0.2266 means 5 or 6 or 7 stretches may be cleared but no less than five stretches will be cleared. For a uniform minefield, clearing at least 5/7 of stretches means at least 71% of the seven mines in the path will be killed (with the computed probability). Table 2 shows that a single sortie has a low probability of clearing very many

Table 2. Least Path Cleared: One Sortie, Uniform Minefield

| Proportion Cleared* | | Probability of Clearing at Least r Stretches | | | |
|---------------------|-----|--|--------|--------|--------|
| (r/7) | (%) | p(30-m) = 0.15 | = 0.30 | = 0.50 | = 0.70 |
| 7/7 | 100 | 0.0000 | 0.0002 | 0.0078 | 0.0824 |
| 6/7 | 86 | 0.0001 | 0.0038 | 0.0625 | 0.3294 |
| 5/7 | 71 | 0.0012 | 0.0288 | 0.2266 | 0.6471 |
| 4/7 | 57 | 0.0121 | 0.1260 | 0.5000 | 0.8740 |
| 3/7 | 43 | 0.0738 | 0.3529 | 0.7734 | 0.9712 |
| 2/7 | 29 | 0.2834 | 0.6706 | 0.9375 | 0.9962 |
| 1/7 | 14 | 0.6794 | 0.9176 | 0.9922 | 0.9998 |
| 0/7 | 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

* The proportion cleared is based on 210 m with seven CBU72 FAE bombs from one Harrier.

stretches. However, the "experiment" (sorties) may be repeated until success (clearing at least r stretches) is reached with any desired certainty.

2.2 Multiple Sorties. Multiple sorties against the same 210-m stretch impressively raise the clearance (cumulative) probability. The reason is that while each sortie is an independent event and the bomb falls are each independent events, the bombing results are not independent. Once a stretch is cleared of mines it remains cleared. The next sortie has the same clearance probabilities as the first (Tables 1 and 2) but the likelihood is that different stretches are cleared and the total cleared stretches can be a high proportion of seven stretches with high probability. The probability function for multiple sorties is derived in Section 7. The great improvement a few sorties make is seen in Table 3 and by comparison with Table 2.

In Appendix A, the breach of a uniform minefield is shown by exact and cumulative probabilities through 30 sorties. An extract of that Appendix is Table 4, which is a most useful result for squadron operations planning because the point of view is not probability (Table 3) but number of sorties required. The number of sorties is manageably small and there are

Table 3. Least Path Cleared: Multiple Sorties, Uniform Minefield

| r Stretches* | Probability of Clearing at Least r Stretches | | | |
|----------------------|--|--------|--------|--------|
| | p(30-m) = 0.15 | = 0.30 | = 0.50 | = 0.70 |
| <u>Two Sorties</u> | | | | |
| 7 | 0.0001 | 0.0090 | 0.1335 | 0.5168 |
| 6 | 0.0024 | 0.0693 | 0.4449 | 0.8745 |
| 5 | 0.0205 | 0.2433 | 0.7564 | 0.9807 |
| 4 | 0.0988 | 0.5219 | 0.9294 | 0.9982 |
| 3 | 0.3026 | 0.7895 | 0.9871 | 0.9999 |
| 2 | 0.6209 | 0.9438 | 0.9987 | 1.0000 |
| 1 | 0.8972 | 0.9932 | 0.9999 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| <u>Three Sorties</u> | | | | |
| 7 | 0.0013 | 0.0528 | 0.3927 | 0.8256 |
| 6 | 0.0155 | 0.2459 | 0.7854 | 0.9860 |
| 5 | 0.0832 | 0.5484 | 0.9537 | 0.9994 |
| 4 | 0.2630 | 0.8115 | 0.9938 | 1.0000 |
| 3 | 0.5490 | 0.9489 | 0.9995 | 1.0000 |
| 2 | 0.8221 | 0.9920 | 1.0000 | 1.0000 |
| 1 | 0.9671 | 0.9994 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| <u>Four Sorties</u> | | | | |
| 7 | 0.0057 | 0.1463 | 0.6365 | 0.9447 |
| 6 | 0.0493 | 0.4699 | 0.9335 | 0.9987 |
| 5 | 0.1921 | 0.7767 | 0.9929 | 1.0000 |
| 4 | 0.4520 | 0.9382 | 0.9995 | 1.0000 |
| 3 | 0.7358 | 0.9893 | 1.0000 | 1.0000 |
| 2 | 0.9217 | 0.9989 | 1.0000 | 1.0000 |
| 1 | 0.9894 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

* Seven stretches amount to 210 m with seven CBU72 FAE bombs from one Harrier.

Table 4. Number of Sorties to Clear at Least X% of Mines With at Least $\gamma\%$ Probability:
Uniform Minefield

| Proportion Cleared* | | Number of Sorties | | | |
|---------------------|------|--------------------------------|--------|--------|--------|
| (r/7) | (X%) | Probability $\gamma \geq 90\%$ | | | |
| | | p(30-m) = 0.15 | = 0.30 | = 0.50 | = 0.70 |
| 7/7 | 100 | 26 | 12 | 7 | 4 |
| 6/7 | 86 | 16 | 8 | 4 | 3 |
| 5/7 | 71 | 11 | 5 | 3 | 2 |
| 4/7 | 57 | 8 | 4 | 2 | 2 |
| 3/7 | 43 | 6 | 3 | 2 | 4 |
| 2/7 | 29 | 4 | 2 | 1 | 1 |
| 1/7 | 14 | 3 | 1 | 1 | 1 |

| (r/7) | (X%) | Probability $\gamma \geq 80\%$ | | | |
|-------|------|--------------------------------|--------|--------|--------|
| | | p(30-m) = 0.15 | = 0.30 | = 0.50 | = 0.70 |
| 7/7 | 100 | 22 | 10 | 5 | 3 |
| 6/7 | 86 | 14 | 6 | 4 | 2 |
| 5/7 | 71 | 10 | 5 | 3 | 2 |
| 4/7 | 57 | 7 | 3 | 2 | 1 |
| 3/7 | 43 | 5 | 3 | 2 | 1 |
| 2/7 | 29 | 3 | 2 | 1 | 1 |
| 1/7 | 14 | 2 | 1 | 1 | 1 |

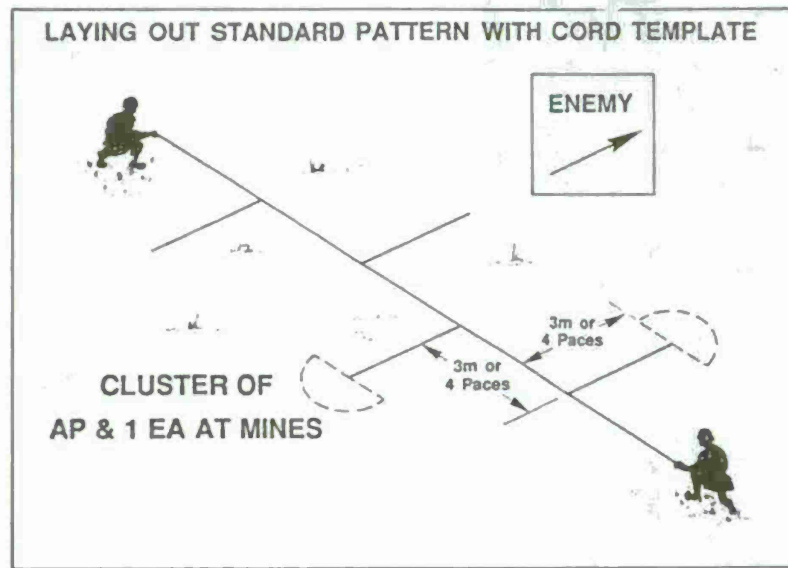
* The proportion cleared is based on 210 m with seven CBU72 FAE bombs in each sortie.

no surprises to the progression. Vertically the number of sorties needed increases as the proportion cleared (with stated probability) increases and as the probability demanded (80% to 90%) increases. Horizontally, the number of sorties needed decreases as the probability of a single FAE bomb breaching 30 meters of minefield increases.

3. NUMBER OF SORTIES: STANDARD MINEFIELD

3.1 Definition. A deliberately laid minefield is patterned to aid mine laying and recovery. The U.S. Army minefield pattern is semistrict (see Figure 3) and is the one we shall try to breach. Basically, mines are in "clusters" of antipersonnel (AP) mines guarding one antitank

FM 20-32 (1976)



THREE REGULAR MINE STRIPS -

STANDARD MINEFIELD PATTERN

MARKING OF SHORT MINE STRIPS OF IOE

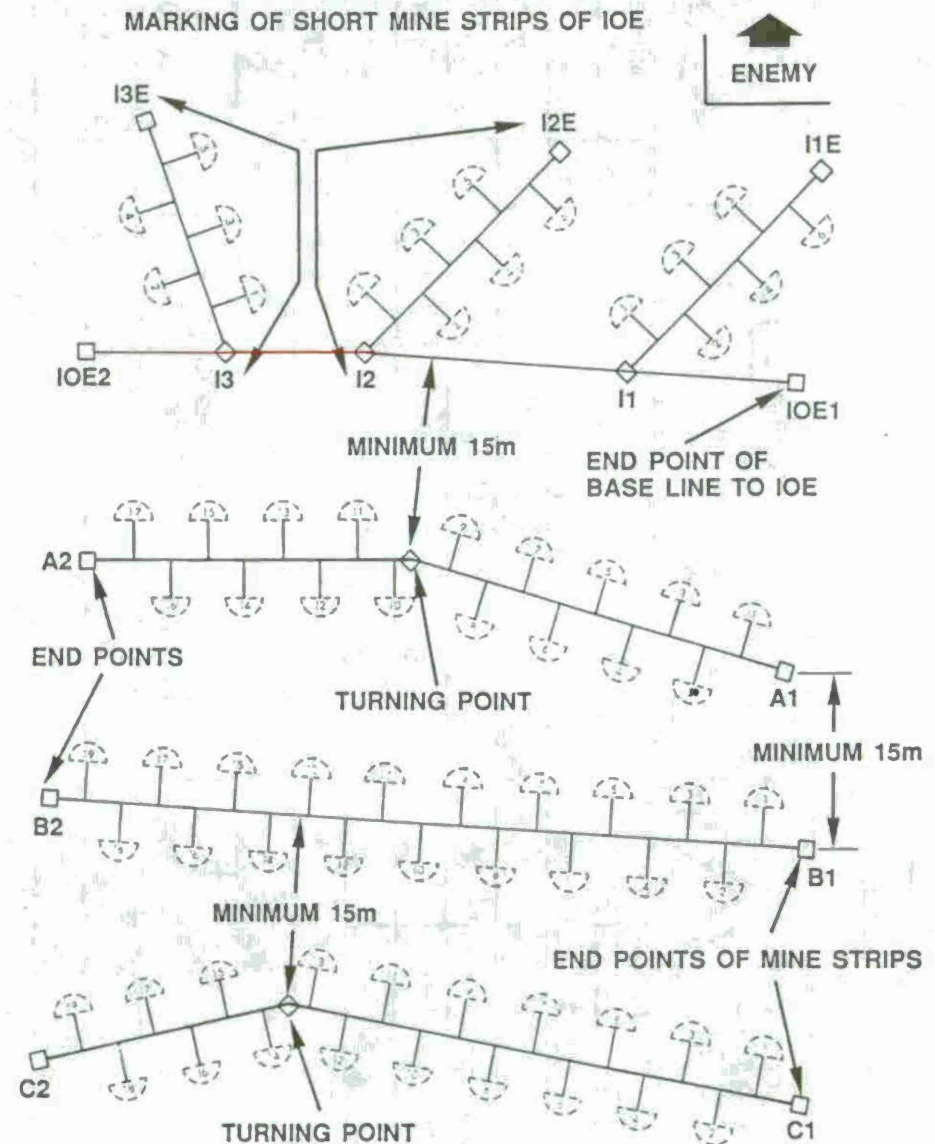


Figure 3. Layout of Standard Minefield.

(AT) mine. A cluster is laid 3 m down and 3 m out, alternately on both sides of a more-or-less straight string line. The whole affair is called a "regular mine strip." The clusters are widely separated to prevent sympathetic detonation (i.e., one AT mine exploding another in a reaction). But, to keep up the minefield density, which determines its probability of kill, several regular mine strips have to be laid. Field Manual 20-32, Table J-1, typically calls for three regular strips behind an "irregular outer edge" (IOE)* for a 1,000-mine/km antitank minefield. As a further deception measure, the officer in charge of the mine laying party is free to put in mine strips that contain no AT mines, only AP mines, but he will have three regular mine strips that do contain AT mines. A ground assault through a minefield will be carried out by armored vehicles, impervious to AP mines, so we are concerned only with AT-containing mine strips in this analysis.

The result of using higher mine densities is to cause more regular mine strips to be laid. But doing that moves the strip pattern closer to the uniform pattern (Figure 2) that was breached in Section 2.

No mathematical difficulty is made if the AT mines are not evenly laid throughout the minefield but are instead located on strips across the bombing path. The general problem is to find the probability of bombing a path through a minefield of strips of AT mines. As an instance of the general problem, we take the Harrier bombload and typical minefield density. There are three mine strips crossing seven stretches to be bombed. There is no way to tell through which stretch a mine strip passes. We stipulate two rules: not more than one mine strip crosses each 30-m bombed stretch and the IOE is dropped. These restrictions are not essential, but they simplify the problem and remove counting ambiguity.

Figure 4 illustrates the situation by showing one of the possible mine strip arrangements across our bombing path. For information only, the number of possible mining arrangements is 35, given by a combinations function, $\binom{7}{3} = \frac{7!}{3!4!} = 35$.

* The IOE is a complicated deception about minefield location and pattern. Extending from the IOE string line are skew branches with a total of 1/3 as many clusters as are on the regular strips. Attackers cross the IOE with few losses and draw into the real minefield and are entrapped.

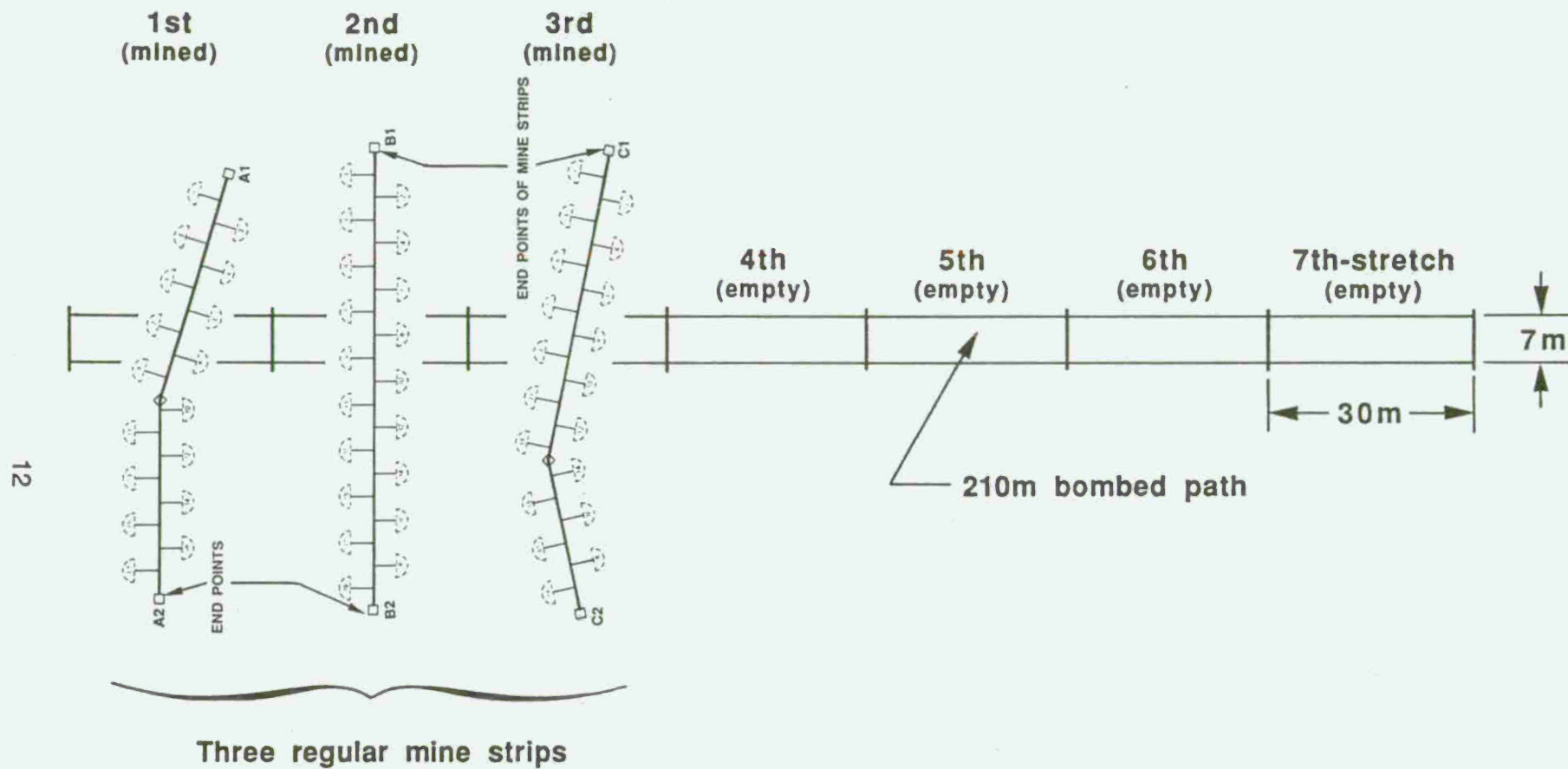


Figure 4. Mine Strips Across Bombed Stretches.

It is unnecessary to list the arrangements or even consider them because every stretch receives a bomb from every sortie. Whether a stretch is mined or not is irrelevant. What matters is the probability that our (less than completely capable FAE) bombs will clear either three, two, one, or zero mine strips.

3.2 Number of Sorties. In Appendix B the breach of a standard minefield is shown by exact and cumulative probabilities through 30 sorties. An extract of that Appendix is Table 5 and is the number of sorties required to (partially) breach the standard minefield. Tables 5 and 4 are analogs. Table 3 makes a point about the importance of multiple sorties and its analog for standard minefields does not need to be given here.

Table 5. Number of Sorties to Clear at Least X% of Mines With at Least $\gamma\%$ Probability: Standard Minefield

| Proportion Cleared* | | Number of Sorties | | | |
|---------------------|------|--------------------------------|----------|----------|----------|
| | | Probability $\gamma \geq 90\%$ | | | |
| | | $p(30-m) = 0.15$ | $= 0.30$ | $= 0.50$ | $= 0.70$ |
| (r/3) | (X%) | | | | |
| 3/3 | 100 | 21 | 10 | 5 | 3 |
| 2/3 | 66 | 11 | 5 | 3 | 2 |
| 1/3 | 33 | 5 | 3 | 2 | 1 |

| Proportion Cleared* | | Probability $\gamma \geq 80\%$ | | | |
|---------------------|------|--------------------------------|----------|----------|----------|
| | | Probability $\gamma \geq 80\%$ | | | |
| | | $p(30-m) = 0.15$ | $= 0.30$ | $= 0.50$ | $= 0.70$ |
| (r/3) | (X%) | | | | |
| 3/3 | 100 | 17 | 8 | 4 | 3 |
| 2/3 | 66 | 8 | 4 | 2 | 2 |
| 1/3 | 33 | 4 | 2 | 1 | 1 |

* The proportion cleared is based on 210 m with seven CBU72 FAE bombs, each sortie.

4. EXPECTED PATH DENSITY AFTER FAE BOMBING

Since we cannot know how many mined stretches are cleared, we calculate the expectation value of the minefield density, \bar{d} .

$$\bar{d} = \sum_{r=0}^k P_r d_r,$$

where P_r is the exact probability of clearing r stretches from Appendix A or B and k is the number of mined stretches. The mine density in the r -th stretch is $d_r = \frac{d_0}{k} (k - r)$, where d_0 is the initial minefield density.

As an example, after four sorties drop bombs which have 0.50 probability of defeating a 30-meter stretch (0.50 weapon drop) on a uniform minefield with an initial density of 1,000 mines/km, the expected density of mines is as given below. (See Appendix A, exact probability.)

$$\begin{aligned}\bar{d} &= \frac{1000}{7} [0.0000(7) + 0.0000(6) + 0.0000(5) + 0.0004(4) \\ &\quad + 0.0066(3) + 0.0594(2) + 0.2970(1) + 0.6365(0)], \\ \bar{d} &= 62.46 \text{ mines/km}.\end{aligned}$$

The expected density amounts to 93% clearance ($1 - 62.4/1000$) in the bombed path.

Repeating the same attack conditions against a standard minefield gives the same expected density as on the uniform minefield. (See Appendix B, exact probability.)

$$\begin{aligned}\bar{d} &= \frac{1000}{3} [0.0002(3) + 0.0110(2) + 0.1648(1) + 0.8240(0)], \\ \bar{d} &= 62.47 \text{ mines/km}.\end{aligned}$$

It is surprising, but has been shown, that minefield pattern has no effect on the long-run clearance to be expected. Thus, pattern has been eliminated in Table 6. Note though that for operations, as compared to long-run plans, Tables 4 and 5 show that the pattern does matter. The standard minefield found in tactical situations sometimes requires less sorties than the uniform minefield of test situations for the same percentage cleared.

We have also found that the expected densities, generated by the defining equation for expected value, are given by this simpler formula:

$$\bar{d} = d_0 [1 - p(30-m)]^n,$$

where d_0 is the unbombed minefield density; here, $d_0 = 1000$ mines/km.

Table 6. Expected Path Density After FAE Bombing

| n Sorties | Mines/km (clearance %) | | | |
|-----------|------------------------|----------|----------|----------|
| | $p(30-m) = 0.15$ | $= 0.30$ | $= 0.50$ | $= 0.70$ |
| 1 | 850 (15) | 700 (30) | 500 (50) | 300 (70) |
| 2 | 722 (28) | 490 (51) | 250 (75) | 90 (91) |
| 3 | 614 (39) | 343 (66) | 125 (88) | 27 (97) |
| 4 | 522 (48) | 240 (76) | 62 (94) | 8 (99) |

The expectation value \bar{d} is the "best" single number to quote as a path density after the requisite number of sorties. However, it is a mathematical value that would occur as an average of FAE strikes (n sorties each) on many, different 210-m paths and would not occur as a result of a single path clearing strike. It is a planning tool but its use, neglecting the cumulative probability tables, could result in tank losses.

5. PROBABILITY OF GETTING THROUGH

The clearance of at least X% of antitank mines can be translated into the probability that a tank will hit (or get through) the mines remaining in the breach path. The translation is made with Figure 5 from FM 20-32 (1976). With clearance already presumed, the result applies without regard for weapon effectiveness.

Table 7 shows various clearance levels and the corresponding mine density in the breach path. The clearance level, with stated probability, depends, of course, on the number of sorties used. Given that one can attain these clearances, the table shows the probability of getting through (and hitting a mine).

Table 7. Probability of a Tank Getting Through the Breach Path

| Clearance* (%) | Path Density (mines/km) | P_{hit} | $P_{get\ through}$ |
|-------------------|----------------------------|-------------|--------------------|
| 100 | 0 | 0 | 1.00 |
| 71 | ≤ 290 | ≤ 0.37 | ≥ 0.63 |
| 66 | ≤ 340 | ≤ 0.40 | ≥ 0.60 |
| 57 | ≤ 430 | ≤ 0.47 | ≥ 0.53 |
| 33 | ≤ 670 | ≤ 0.61 | ≥ 0.39 |

* The probability of attaining these percentages increases as the number of sorties increases. (See Appendices.)

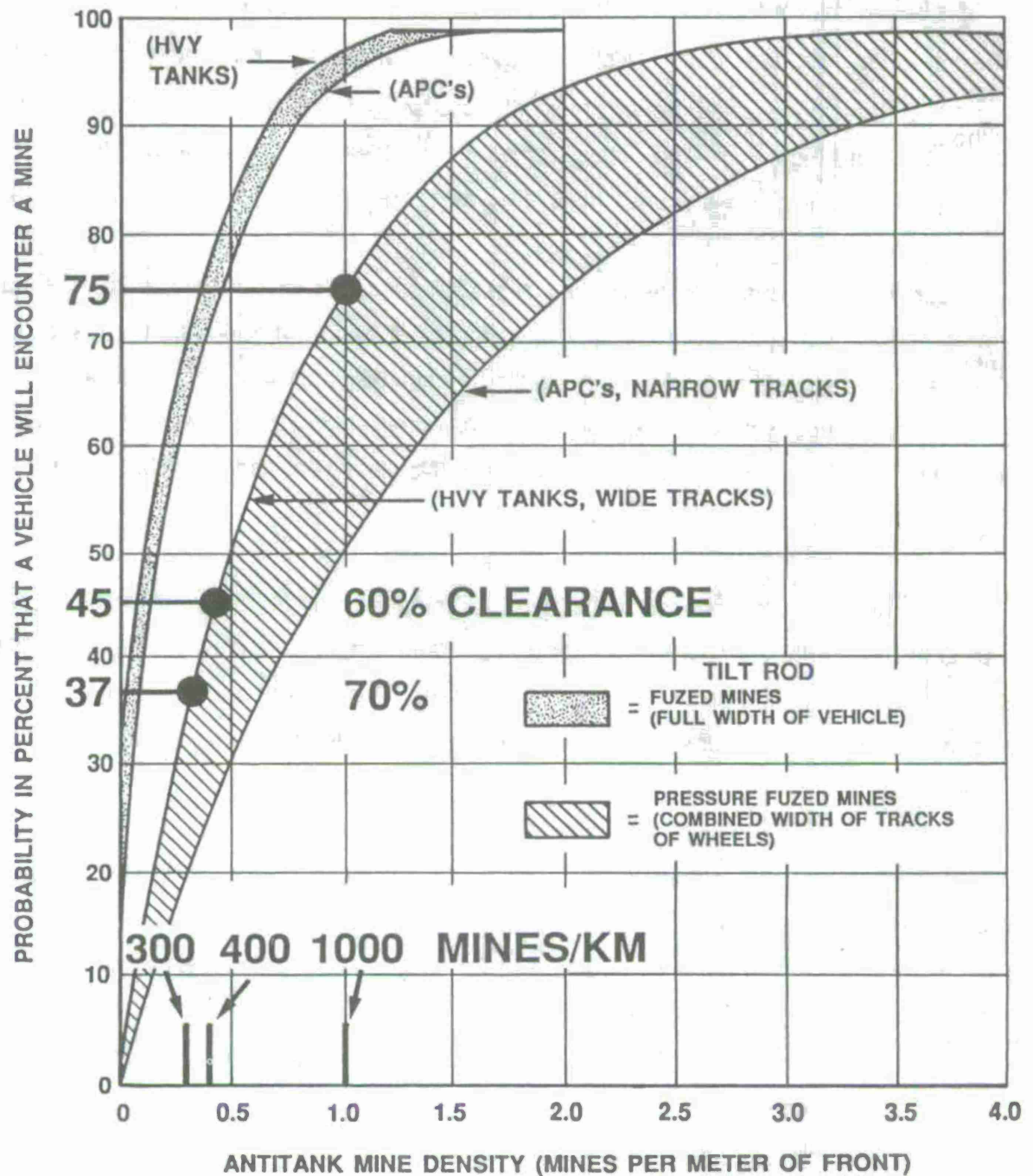


Figure 5. Probability of Tanks Hitting Mines.

6. PARTIAL CLEARANCE AND BULLING THROUGH

In a barrier minefield, a density of 1,000 mines/km is reasonable. A breach in the field is only a one-way, one-lane path and so a width of 7 m for tanks is reasonable.* Across this "front" there are, on average, seven mines. Of course, they are in a depth which may be 100–300 m (see Figure 2). The density almost guarantees that a tank will hit one if it tries to cross the minefield; the maximum loss is seven tanks.

Ordering certain death for the first few tanks is unacceptable to American commanders. That is, "bulling through" is not an acceptable tactic. It may be argued that the losses are less with this tactic than they would be if the tanks go cautiously, slowly, with plows because the minefield is covered with enemy guns and long exposure to fire guarantees heavy losses of the tanks. However, the selection of the tanks that go first—and die—in a bulling tactic is too grievous to do.

We argue that an acceptable tactic is to use some partially effective breaching means and then to bull through. A better tactic after partial breaching, if the enemy fire is suppressed, is to put plows or rollers on the first and second tank. A complementary benefit to the mechanical devices supplementing the partial breaching means is that the rollers will contact fewer explosives.

To understand why we consider "partial clearance," recall the results of Table 5 for a standard minefield. The FAE discussions and calculations showed that with a poor bomb, one having $p(30\text{-m}) = 0.30$, it would take 8–10 sorties to kill 100% of the mines in the lane of 210 m. Because this number of sorties is not small and repeated attacks jeopardize the airmen, we must consider partial clearance. At 66% clearance, the number of sorties drops to four, and 33% clearance requires only two sorties (Table 5, $\gamma \geq 80\%$). Although we are writing about only FAE, we are skeptical that any countermine breaching system is both fast and completely effective.

* FM 20-32 uses 8 m as a breach width.

We now argue that bulling through the minefield on the partially opened path will be acceptable. Suppose the sorties are few and the bombs only weakly effective, then the strike cannot be more than partially effective. Table 5 shows that four or five sorties carrying the 0.30 weapons are needed for 66% clearance with high probability. The remaining 34% of mines will not cause us, the attacker, heavy loss. Neither is the lead tank made a sacrifice. Leaving 34% of the mines alive sounds unacceptable, but that is the deception of percentages. It is necessary to change our thoughts from percentages to actual numbers of mines. The number of mines in the 7-m-wide breach is seven before FAE sorties and less than three (0.34×7) afterward on average. The effect is that the minefield density in the path is reduced from 1,000 mines/km to 340 mines/km (not 230), and the countermine manual (Figure 5) shows that the tank probability of hitting a mine is down from 0.75 to 0.40. The odds (3 to 2) slightly favor that it will get through if it just bulls its way. If the lead tank gets through, all get through since they move on the narrow lane like elephants on parade. The maximum loss is three tanks.

Table 8 shows that against 1,000 mines/km, with a $p(30\text{-m}) = 0.30$, four or five sorties give a 3 in 5 chance that the first tank gets through; zero sorties give 1 in 4 chances that it gets through. The combined tactic of partially clearing the path and bulling through is shown to be effective over bulling alone.

Table 8. Probability of a Tank Getting Through the Breach Path
(With Less Effective Bombs)

| No. of Sorties ^a | Clearance → Minefield (%) (mines/km) | $P_{\text{hit mine}}^b$ | $P_{\text{get through}}$ |
|-----------------------------|---|-------------------------|--------------------------|
| 0 | 0 → 1,000 | 0.75 | 0.25 |
| 2-3 | 33 → 670 | 0.61 | 0.39 |
| 4-5 | 66 → 340 | 0.40 | 0.60 |
| 0 | 0 → 2,000 | 0.93 | 0.07 |
| 2-3 | 33 → 1340 | 0.84 | 0.16 |
| 4-5 | 66 → 680 | 0.61 | 0.39 |

^a 80-90% probability of stated percent clearance and $p(30\text{-m}) = 0.30$

^b Figure 5

7. DERIVATION OF MULTIPLE SORTIES PROBABILITY

The binomial distribution cannot give probabilities of clearing beyond one sortie, directly. The result for following sorties depends on what happened before. The independence of outcomes on each trial (sortie) is violated and that is a condition for using the binomial distribution.

In a mined stretch there are only two outcomes for bombing—clearing all mines or not clearing all mines in that stretch. Each bomb falling on that stretch has a constant probability of success say $1/2$. The probability of not clearing this stretch is the complement, also $1/2$. The probability of not clearing this stretch in, say four sorties, is: $(1/2)^4 = 1/16$. Again, the probability of the only other outcome is the complement. So, the probability of clearing that stretch with four sorties is $1 - 1/16 = 15/16$. Assume we have a standard minefield of 1,000 mines/km which forces the antitank mines to be in three separate strips blocking the field. Then, there are three stretches that hold mines (recall Figure 4). At this point we can resume using the binomial distribution. Since each of the stretches is independent, the probability of clearing all three stretches is: $(15/16)^3 = 0.8240$. The probability of clearing only two stretches is the summed probability of all the sub-events: clearing two stretches $(15/16)^2$ and not clearing one stretch $(1/16)$. There are $\binom{3}{2} = 3$ ways of clearing two out of three stretches. All total, the probability of clearing two stretches is $3 (15/16)^2 (1/16) = 0.1648$. Similarly, the probability of clearing only one mined stretch is: $\binom{3}{1} (15/16) (1/16)^2 = 3 (15/16) (1/16)^2 = 0.0110$. The probability of clearing none of the three mined stretches in four sorties is: $(1/16)^3 = 0.0002$.

This argument can be generalized as follows. Let:

n = number of sorties,

k = number of mined stretches,

r = number of mined stretches to be cleared,

$p(30-m)$ = probability of clearing one mined stretch with one bomb,

P_n = probability of clearing one mined stretch with n sorties,

$P_n^c = 1 - P_n$ = probability of not clearing one mined stretch with n sorties,

P_r = probability of clearing exactly r mined stretches.

Then,

$$P_n^c = [1 - p(30-m)]^n,$$

$$P_n = 1 - [1 - p(30-m)]^n,$$

$$P_r = \binom{k}{r} (P_n)^r (P_n^c)^{k-r}.$$

This formulation gives exact probabilities for sortie numbers including one, where it matches the binomial distribution. For the uniform minefield, $k = 7$ (Appendix A) and for the standard minefield, $k = 3$ (Appendix B).

8. CONSIDERATIONS

Four sorties is a feasible number to request. However, the planes must bomb the same 210-m stretch. The pilot's problem is to put the bombsight cross hairs on the beginning of the stretch and fly to the other end as the computer releases the bombs. It is not stated how this stretch is selected or marked. Possibly smoke shell at both ends or a shell crater at both ends or a line charge rut could be used in daylight bombing. The idea is that the planes must find and line up on two points, not one, in order to bomb the same stretch. A formation drop like Leonard used would, with FAE, cause cloud burns, so the four sorties must be time-separated, all coming in the same way. Pilots prefer to bomb from different directions so as not to give anti-aircraft gunners a predictable flight path. The close air support maxim of "one pass and haul ass" is violated. The resolution might be that a breach operation would not be contemplated without local air and ground superiority.

Another drawback is that pressure-fuzed mines are a large subset of all mines likely to be laid. However, military doctrine dictates that fuze types not be mixed, because doing otherwise complicates safing and recovery of one's own mines. So at least one minefield, pressure-fuzed, would be susceptible to FAE.

A bomb visually and ballistically like the CBU72 is the CBU88 "Smokeye," which dispenses a huge smoke cloud. These bombs could be dropped for curtain protection before the bombing runs and when the armor moves through.

Finally, FAE has notable effectiveness against many targets, including entrenched infantry. It might be judged a better offense to expend the FAE bombs against other available targets, but the low number of sorties (bombs) taken for minefield breaching would not preclude other worthwhile missions.

9. SUMMARY

The idea of breaching a minefield by bombing was analyzed with probability theory. The length of the breach was set by the nature of the bombs and the number carried on the plane. The outcome of one bombing run for killing mines (a sortie) was given by the binomial distribution, which depends on a bomb's probability of kill within a set distance. The effect of multiple sorties was analyzed with a function derived herein. The probabilities of breaching a uniform and a standard minefield were calculated for four different bomb-effectiveness values for up to 30 sorties.

Based on these results, it is feasible to use tactical bombers to breach a minefield if minefield marking can be accomplished. Furthermore, information definite enough for operations planning has emerged. The general method will solve other bombing-breaching problems.

For definiteness, fuel-air explosive bombs were notionally put on Harrier aircraft. Historically, FAE is effective against the largest subset of mines—pressure-fuzed mines. For narrow, parochial reasons, FAE is actually being dropped from the inventory.

In one instance, FAE bombs were dropped on live minefields, which gave rational, though not precise, choices for a single bomb's success in a set distance. Similar information may not exist for iron bombs. The probability analysis yielded exact and cumulative probabilities and numbers of sorties to kill mines hidden across the bombing path. It made no difference in the long run whether the mines were evenly laid in depth or bunched into strips. The

expectation is that four Harrier sorties (4 x 7 CBU72 FAE bombs) with bombs of probability of kill equal to 0.50 in 30 meters would give 94% clearance of mines, ample to give near certainty of tanks getting through. In distinction from the expectation, a particular four-sortie strike on a standard minefield has probability 0.824 of 100% clearance of mines in the bombing path. The analysis further found that partial clearance (caused by poor bombs or too few sorties) reduced the mine density so much that not more than three tanks could hit mines. For high clearance the required number of sorties was low enough to be fair to the airmen.

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APPENDIX A:

EXACT AND CUMULATIVE PROBABILITIES OF BREACHING A UNIFORM MINEFIELD

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Table A-1. Exact Probabilities of Breaching
a Uniform Minefield

n = 1

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0000 | 0.0002 | 0.0078 | 0.0824 |
| 6 | 0.0001 | 0.0036 | 0.0547 | 0.2471 |
| 5 | 0.0012 | 0.0250 | 0.1641 | 0.3177 |
| 4 | 0.0109 | 0.0972 | 0.2734 | 0.2269 |
| 3 | 0.0617 | 0.2269 | 0.2734 | 0.0972 |
| 2 | 0.2097 | 0.3177 | 0.1641 | 0.0250 |
| 1 | 0.3960 | 0.2471 | 0.0547 | 0.0036 |
| 0 | 0.3206 | 0.0824 | 0.0078 | 0.0002 |

n = 2

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0001 | 0.0090 | 0.1335 | 0.5168 |
| 6 | 0.0023 | 0.0604 | 0.3115 | 0.3578 |
| 5 | 0.0180 | 0.1740 | 0.3115 | 0.1061 |
| 4 | 0.0783 | 0.2786 | 0.1730 | 0.0175 |
| 3 | 0.2038 | 0.2676 | 0.0577 | 0.0017 |
| 2 | 0.3184 | 0.1543 | 0.0115 | 0.0001 |
| 1 | 0.2763 | 0.0494 | 0.0013 | 0.0000 |
| 0 | 0.1028 | 0.0068 | 0.0001 | 0.0000 |

n = 3

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0013 | 0.0528 | 0.3927 | 0.8256 |
| 6 | 0.0142 | 0.1931 | 0.3927 | 0.1604 |
| 5 | 0.0678 | 0.3024 | 0.1683 | 0.0134 |
| 4 | 0.1797 | 0.2632 | 0.0401 | 0.0006 |
| 3 | 0.2860 | 0.1374 | 0.0057 | 0.0000 |
| 2 | 0.2731 | 0.0430 | 0.0005 | 0.0000 |
| 1 | 0.1449 | 0.0075 | 0.0000 | 0.0000 |
| 0 | 0.0329 | 0.0006 | 0.0000 | 0.0000 |

n = 4

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0057 | 0.1463 | 0.6365 | 0.9447 |
| 6 | 0.0436 | 0.3236 | 0.2970 | 0.0540 |
| 5 | 0.1428 | 0.3068 | 0.0594 | 0.0013 |
| 4 | 0.2599 | 0.1615 | 0.0066 | 0.0000 |
| 3 | 0.2838 | 0.0510 | 0.0004 | 0.0000 |
| 2 | 0.1860 | 0.0097 | 0.0000 | 0.0000 |
| 1 | 0.0677 | 0.0010 | 0.0000 | 0.0000 |
| 0 | 0.0106 | 0.0000 | 0.0000 | 0.0000 |

Table A-1. Exact Probabilities of Breaching
a Uniform Minefield (continued)

n = 5

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0165 | 0.2758 | 0.8007 | 0.9831 |
| 6 | 0.0920 | 0.3900 | 0.1808 | 0.0168 |
| 5 | 0.2203 | 0.2364 | 0.0175 | 0.0001 |
| 4 | 0.2928 | 0.0796 | 0.0009 | 0.0000 |
| 3 | 0.2335 | 0.0161 | 0.0000 | 0.0000 |
| 2 | 0.1118 | 0.0019 | 0.0000 | 0.0000 |
| 1 | 0.0297 | 0.0001 | 0.0000 | 0.0000 |
| 0 | 0.0034 | 0.0000 | 0.0000 | 0.0000 |

n = 6

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0364 | 0.4164 | 0.8956 | 0.9949 |
| 6 | 0.1541 | 0.3886 | 0.0995 | 0.0051 |
| 5 | 0.2800 | 0.1555 | 0.0047 | 0.0000 |
| 4 | 0.2826 | 0.0345 | 0.0001 | 0.0000 |
| 3 | 0.1711 | 0.0046 | 0.0000 | 0.0000 |
| 2 | 0.0622 | 0.0004 | 0.0000 | 0.0000 |
| 1 | 0.0125 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0011 | 0.0000 | 0.0000 | 0.0000 |

n = 7

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0668 | 0.5479 | 0.9466 | 0.9985 |
| 6 | 0.2207 | 0.3442 | 0.0522 | 0.0015 |
| 5 | 0.3125 | 0.0927 | 0.0012 | 0.0000 |
| 4 | 0.2457 | 0.0139 | 0.0000 | 0.0000 |
| 3 | 0.1159 | 0.0012 | 0.0000 | 0.0000 |
| 2 | 0.0328 | 0.0001 | 0.0000 | 0.0000 |
| 1 | 0.0052 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0003 | 0.0000 | 0.0000 | 0.0000 |

n = 8

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.1079 | 0.6599 | 0.9730 | 0.9995 |
| 6 | 0.2828 | 0.2826 | 0.0267 | 0.0005 |
| 5 | 0.3178 | 0.0519 | 0.0003 | 0.0000 |
| 4 | 0.1984 | 0.0053 | 0.0000 | 0.0000 |
| 3 | 0.0743 | 0.0003 | 0.0000 | 0.0000 |
| 2 | 0.0167 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0021 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |

Table A-1. Exact Probabilities of Breaching
a Uniform Minefield (continued)

n = 9

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.1581 | 0.7495 | 0.9864 | 0.9999 |
| 6 | 0.3337 | 0.2206 | 0.0135 | 0.0001 |
| 5 | 0.3018 | 0.0278 | 0.0001 | 0.0000 |
| 4 | 0.1516 | 0.0020 | 0.0000 | 0.0000 |
| 3 | 0.0457 | 0.0001 | 0.0000 | 0.0000 |
| 2 | 0.0083 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0008 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 10

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.2155 | 0.8183 | 0.9932 | 1.0000 |
| 6 | 0.3698 | 0.1665 | 0.0068 | 0.0000 |
| 5 | 0.2720 | 0.0145 | 0.0000 | 0.0000 |
| 4 | 0.1111 | 0.0007 | 0.0000 | 0.0000 |
| 3 | 0.0272 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0040 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0003 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 11

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.2775 | 0.8695 | 0.9966 | 1.0000 |
| 6 | 0.3904 | 0.1228 | 0.0034 | 0.0000 |
| 5 | 0.2354 | 0.0074 | 0.0000 | 0.0000 |
| 4 | 0.0788 | 0.0002 | 0.0000 | 0.0000 |
| 3 | 0.0158 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0019 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 12

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.3416 | 0.9070 | 0.9983 | 1.0000 |
| 6 | 0.3966 | 0.0891 | 0.0017 | 0.0000 |
| 5 | 0.1973 | 0.0038 | 0.0000 | 0.0000 |
| 4 | 0.0545 | 0.0001 | 0.0000 | 0.0000 |
| 3 | 0.0090 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0009 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table A-1. Exact Probabilities of Breaching
a Uniform Minefield (continued)

n = 13

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.4057 | 0.9341 | 0.9991 | 1.0000 |
| 6 | 0.3906 | 0.0640 | 0.0009 | 0.0000 |
| 5 | 0.1612 | 0.0019 | 0.0000 | 0.0000 |
| 4 | 0.0369 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0051 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0004 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 14

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.4681 | 0.9535 | 0.9996 | 1.0000 |
| 6 | 0.3753 | 0.0456 | 0.0004 | 0.0000 |
| 5 | 0.1290 | 0.0009 | 0.0000 | 0.0000 |
| 4 | 0.0246 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0028 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 15

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.5274 | 0.9672 | 0.9998 | 1.0000 |
| 6 | 0.3533 | 0.0323 | 0.0002 | 0.0000 |
| 5 | 0.1015 | 0.0005 | 0.0000 | 0.0000 |
| 4 | 0.0162 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0015 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 16

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.5827 | 0.9770 | 0.9999 | 1.0000 |
| 6 | 0.3272 | 0.0228 | 0.0001 | 0.0000 |
| 5 | 0.0787 | 0.0002 | 0.0000 | 0.0000 |
| 4 | 0.0105 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0008 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table A-1. Exact Probabilities of Breaching
a Uniform Minefield (continued)

n = 17

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.6336 | 0.9838 | 0.9999 | 1.0000 |
| 6 | 0.2988 | 0.0161 | 0.0001 | 0.0000 |
| 5 | 0.0604 | 0.0001 | 0.0000 | 0.0000 |
| 4 | 0.0068 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0005 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 18

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.6798 | 0.9887 | 1.0000 | 1.0000 |
| 6 | 0.2697 | 0.0113 | 0.0000 | 0.0000 |
| 5 | 0.0459 | 0.0001 | 0.0000 | 0.0000 |
| 4 | 0.0043 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 19

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.7213 | 0.9920 | 1.0000 | 1.0000 |
| 6 | 0.2412 | 0.0079 | 0.0000 | 0.0000 |
| 5 | 0.0346 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0028 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 20

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.7583 | 0.9944 | 1.0000 | 1.0000 |
| 6 | 0.2140 | 0.0056 | 0.0000 | 0.0000 |
| 5 | 0.0259 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0017 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table A-1. Exact Probabilities of Breaching
a Uniform Minefield (continued)

n = 21

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.7910 | 0.9961 | 1.0000 | 1.0000 |
| 6 | 0.1886 | 0.0039 | 0.0000 | 0.0000 |
| 5 | 0.0193 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0011 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 22

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.8197 | 0.9973 | 1.0000 | 1.0000 |
| 6 | 0.1653 | 0.0027 | 0.0000 | 0.0000 |
| 5 | 0.0143 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0007 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 23

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.8448 | 0.9981 | 1.0000 | 1.0000 |
| 6 | 0.1442 | 0.0019 | 0.0000 | 0.0000 |
| 5 | 0.0105 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0004 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 24

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.8667 | 0.9987 | 1.0000 | 1.0000 |
| 6 | 0.1253 | 0.0013 | 0.0000 | 0.0000 |
| 5 | 0.0078 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0003 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table A-1. Exact Probabilities of Breaching
a Uniform Minefield (continued)

n = 25

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.8857 | 0.9991 | 1.0000 | 1.0000 |
| 6 | 0.1085 | 0.0009 | 0.0000 | 0.0000 |
| 5 | 0.0057 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 26

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9021 | 0.9993 | 1.0000 | 1.0000 |
| 6 | 0.0937 | 0.0007 | 0.0000 | 0.0000 |
| 5 | 0.0042 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 27

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9162 | 0.9995 | 1.0000 | 1.0000 |
| 6 | 0.0807 | 0.0005 | 0.0000 | 0.0000 |
| 5 | 0.0030 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 28

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9284 | 0.9997 | 1.0000 | 1.0000 |
| 6 | 0.0694 | 0.0003 | 0.0000 | 0.0000 |
| 5 | 0.0022 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table A-1. Exact Probabilities of Breaching
a Uniform Minefield (continued)

n = 29

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9388 | 0.9998 | 1.0000 | 1.0000 |
| 6 | 0.0595 | 0.0002 | 0.0000 | 0.0000 |
| 5 | 0.0016 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 30

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9478 | 0.9998 | 1.0000 | 1.0000 |
| 6 | 0.0510 | 0.0002 | 0.0000 | 0.0000 |
| 5 | 0.0012 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table A-2. Cumulative Probabilities of Breaching
a Uniform Minefield

| n = 1 | | | | |
|----------------------|---------|--------|--------|--------|
| Cleared Stretches | p(30-m) | | | |
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0000 | 0.0002 | 0.0078 | 0.0824 |
| 6 | 0.0001 | 0.0038 | 0.0625 | 0.3294 |
| 5 | 0.0012 | 0.0288 | 0.2266 | 0.6471 |
| 4 | 0.0121 | 0.1260 | 0.5000 | 0.8740 |
| 3 | 0.0738 | 0.3529 | 0.7734 | 0.9712 |
| 2 | 0.2834 | 0.6706 | 0.9375 | 0.9962 |
| 1 | 0.6794 | 0.9176 | 0.9922 | 0.9998 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 2 | | | | |
|----------------------|---------|--------|--------|--------|
| Cleared Stretches | p(30-m) | | | |
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0001 | 0.0090 | 0.1335 | 0.5168 |
| 6 | 0.0024 | 0.0693 | 0.4449 | 0.8745 |
| 5 | 0.0205 | 0.2433 | 0.7564 | 0.9807 |
| 4 | 0.0988 | 0.5219 | 0.9294 | 0.9982 |
| 3 | 0.3026 | 0.7895 | 0.9871 | 0.9999 |
| 2 | 0.6209 | 0.9438 | 0.9987 | 1.0000 |
| 1 | 0.8972 | 0.9932 | 0.9999 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 3 | | | | |
|----------------------|---------|--------|--------|--------|
| Cleared Stretches | p(30-m) | | | |
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0013 | 0.0528 | 0.3927 | 0.8256 |
| 6 | 0.0155 | 0.2459 | 0.7854 | 0.9860 |
| 5 | 0.0832 | 0.5484 | 0.9537 | 0.9994 |
| 4 | 0.2630 | 0.8115 | 0.9938 | 1.0000 |
| 3 | 0.5490 | 0.9489 | 0.9995 | 1.0000 |
| 2 | 0.8221 | 0.9920 | 1.0000 | 1.0000 |
| 1 | 0.9671 | 0.9994 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 4 | | | | |
|----------------------|---------|--------|--------|--------|
| Cleared Stretches | p(30-m) | | | |
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0057 | 0.1463 | 0.6365 | 0.9447 |
| 6 | 0.0493 | 0.4699 | 0.9335 | 0.9987 |
| 5 | 0.1921 | 0.7767 | 0.9929 | 1.0000 |
| 4 | 0.4520 | 0.9382 | 0.9995 | 1.0000 |
| 3 | 0.7358 | 0.9893 | 1.0000 | 1.0000 |
| 2 | 0.9217 | 0.9989 | 1.0000 | 1.0000 |
| 1 | 0.9894 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table A-2. Cumulative Probabilities of Breaching
a Uniform Minefield (continued)

n = 5

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0165 | 0.2758 | 0.8007 | 0.9831 |
| 6 | 0.1085 | 0.6658 | 0.9815 | 0.9999 |
| 5 | 0.3288 | 0.9022 | 0.9990 | 1.0000 |
| 4 | 0.6216 | 0.9818 | 1.0000 | 1.0000 |
| 3 | 0.8551 | 0.9979 | 1.0000 | 1.0000 |
| 2 | 0.9669 | 0.9999 | 1.0000 | 1.0000 |
| 1 | 0.9966 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 6

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0364 | 0.4164 | 0.8956 | 0.9949 |
| 6 | 0.1905 | 0.8050 | 0.9951 | 1.0000 |
| 5 | 0.4705 | 0.9605 | 0.9999 | 1.0000 |
| 4 | 0.7531 | 0.9950 | 1.0000 | 1.0000 |
| 3 | 0.9242 | 0.9996 | 1.0000 | 1.0000 |
| 2 | 0.9864 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 0.9989 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 7

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.0668 | 0.5479 | 0.9466 | 0.9985 |
| 6 | 0.2876 | 0.8921 | 0.9988 | 1.0000 |
| 5 | 0.6000 | 0.9848 | 1.0000 | 1.0000 |
| 4 | 0.8457 | 0.9987 | 1.0000 | 1.0000 |
| 3 | 0.9617 | 0.9999 | 1.0000 | 1.0000 |
| 2 | 0.9945 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 0.9997 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 8

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.1079 | 0.6599 | 0.9730 | 0.9995 |
| 6 | 0.3907 | 0.9425 | 0.9997 | 1.0000 |
| 5 | 0.7084 | 0.9944 | 1.0000 | 1.0000 |
| 4 | 0.9068 | 0.9997 | 1.0000 | 1.0000 |
| 3 | 0.9811 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 0.9978 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table A-2. Cumulative Probabilities of Breaching
a Uniform Minefield (continued)

| n = 9 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | | 0.1581 | 0.7495 | 0.9864 | 0.9999 |
| 6 | | 0.4918 | 0.9701 | 0.9999 | 1.0000 |
| 5 | | 0.7936 | 0.9980 | 1.0000 | 1.0000 |
| 4 | | 0.9452 | 0.9999 | 1.0000 | 1.0000 |
| 3 | | 0.9909 | 1.0000 | 1.0000 | 1.0000 |
| 2 | | 0.9991 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 10 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | | 0.2155 | 0.8183 | 0.9932 | 1.0000 |
| 6 | | 0.5853 | 0.9848 | 1.0000 | 1.0000 |
| 5 | | 0.8573 | 0.9993 | 1.0000 | 1.0000 |
| 4 | | 0.9684 | 1.0000 | 1.0000 | 1.0000 |
| 3 | | 0.9957 | 1.0000 | 1.0000 | 1.0000 |
| 2 | | 0.9997 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 11 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | | 0.2775 | 0.8695 | 0.9966 | 1.0000 |
| 6 | | 0.6679 | 0.9923 | 1.0000 | 1.0000 |
| 5 | | 0.9033 | 0.9997 | 1.0000 | 1.0000 |
| 4 | | 0.9821 | 1.0000 | 1.0000 | 1.0000 |
| 3 | | 0.9980 | 1.0000 | 1.0000 | 1.0000 |
| 2 | | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 12 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | | 0.3416 | 0.9070 | 0.9983 | 1.0000 |
| 6 | | 0.7382 | 0.9962 | 1.0000 | 1.0000 |
| 5 | | 0.9355 | 0.9999 | 1.0000 | 1.0000 |
| 4 | | 0.9900 | 1.0000 | 1.0000 | 1.0000 |
| 3 | | 0.9990 | 1.0000 | 1.0000 | 1.0000 |
| 2 | | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table A-2. Cumulative Probabilities of Breaching
a Uniform Minefield (continued)

| n = 13 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | | 0.4057 | 0.9341 | 0.9991 | 1.0000 |
| 6 | | 0.7964 | 0.9981 | 1.0000 | 1.0000 |
| 5 | | 0.9575 | 1.0000 | 1.0000 | 1.0000 |
| 4 | | 0.9945 | 1.0000 | 1.0000 | 1.0000 |
| 3 | | 0.9996 | 1.0000 | 1.0000 | 1.0000 |
| 2 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 14 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | | 0.4681 | 0.9535 | 0.9996 | 1.0000 |
| 6 | | 0.8434 | 0.9991 | 1.0000 | 1.0000 |
| 5 | | 0.9724 | 1.0000 | 1.0000 | 1.0000 |
| 4 | | 0.9970 | 1.0000 | 1.0000 | 1.0000 |
| 3 | | 0.9998 | 1.0000 | 1.0000 | 1.0000 |
| 2 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 15 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | | 0.5274 | 0.9672 | 0.9998 | 1.0000 |
| 6 | | 0.8807 | 0.9995 | 1.0000 | 1.0000 |
| 5 | | 0.9822 | 1.0000 | 1.0000 | 1.0000 |
| 4 | | 0.9984 | 1.0000 | 1.0000 | 1.0000 |
| 3 | | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 2 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 16 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | | 0.5827 | 0.9770 | 0.9999 | 1.0000 |
| 6 | | 0.9099 | 0.9998 | 1.0000 | 1.0000 |
| 5 | | 0.9886 | 1.0000 | 1.0000 | 1.0000 |
| 4 | | 0.9991 | 1.0000 | 1.0000 | 1.0000 |
| 3 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table A-2. Cumulative Probabilities of Breaching
a Uniform Minefield (continued)

n = 17

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.6336 | 0.9838 | 0.9999 | 1.0000 |
| 6 | 0.9324 | 0.9999 | 1.0000 | 1.0000 |
| 5 | 0.9927 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 0.9995 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 18

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.6798 | 0.9887 | 1.0000 | 1.0000 |
| 6 | 0.9495 | 0.9999 | 1.0000 | 1.0000 |
| 5 | 0.9954 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 0.9997 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 19

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.7213 | 0.9920 | 1.0000 | 1.0000 |
| 6 | 0.9625 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9971 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 20

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.7583 | 0.9944 | 1.0000 | 1.0000 |
| 6 | 0.9723 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9982 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table A-2. Cumulative Probabilities of Breaching
a Uniform Minefield (continued)

n = 21

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.7910 | 0.9961 | 1.0000 | 1.0000 |
| 6 | 0.9796 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9989 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 22

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.8197 | 0.9973 | 1.0000 | 1.0000 |
| 6 | 0.9850 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9993 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 23

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.8448 | 0.9981 | 1.0000 | 1.0000 |
| 6 | 0.9890 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9996 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 24

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.8667 | 0.9987 | 1.0000 | 1.0000 |
| 6 | 0.9920 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9997 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table A-2. Cumulative Probabilities of Breaching
a Uniform Minefield (continued)

n = 25

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.8857 | 0.9991 | 1.0000 | 1.0000 |
| 6 | 0.9941 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9998 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 26

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9021 | 0.9993 | 1.0000 | 1.0000 |
| 6 | 0.9957 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 27

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9162 | 0.9995 | 1.0000 | 1.0000 |
| 6 | 0.9969 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 28

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9284 | 0.9997 | 1.0000 | 1.0000 |
| 6 | 0.9977 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table A-2. Cumulative Probabilities of Breaching
a Uniform Minefield (continued)

n = 29

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9388 | 0.9998 | 1.0000 | 1.0000 |
| 6 | 0.9984 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 30

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 7 | 0.9478 | 0.9998 | 1.0000 | 1.0000 |
| 6 | 0.9988 | 1.0000 | 1.0000 | 1.0000 |
| 5 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

APPENDIX B:

EXACT AND CUMULATIVE PROBABILITIES OF BREACHING A STANDARD MINEFIELD

INTENTIONALLY LEFT BLANK.

Table B-1. Exact Probabilities of Breaching
a Standard Minefield

| n = 1 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.0034 | 0.0270 | 0.1250 | 0.3430 |
| 2 | | 0.0574 | 0.1890 | 0.3750 | 0.4410 |
| 1 | | 0.3251 | 0.4410 | 0.3750 | 0.1890 |
| 0 | | 0.6141 | 0.3430 | 0.1250 | 0.0270 |

| n = 2 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.0214 | 0.1327 | 0.4219 | 0.7536 |
| 2 | | 0.1669 | 0.3823 | 0.4219 | 0.2236 |
| 1 | | 0.4346 | 0.3674 | 0.1406 | 0.0221 |
| 0 | | 0.3771 | 0.1176 | 0.0156 | 0.0007 |

| n = 3 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.0575 | 0.2836 | 0.6699 | 0.9212 |
| 2 | | 0.2743 | 0.4442 | 0.2871 | 0.0767 |
| 1 | | 0.4366 | 0.2319 | 0.0410 | 0.0021 |
| 0 | | 0.2316 | 0.0404 | 0.0020 | 0.0000 |

| n = 4 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.1092 | 0.4388 | 0.8240 | 0.9759 |
| 2 | | 0.3578 | 0.4159 | 0.1648 | 0.0239 |
| 1 | | 0.3907 | 0.1314 | 0.0110 | 0.0002 |
| 0 | | 0.1422 | 0.0138 | 0.0002 | 0.0000 |

| n = 5 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.1722 | 0.5758 | 0.9091 | 0.9927 |
| 2 | | 0.4119 | 0.3490 | 0.0880 | 0.0073 |
| 1 | | 0.3286 | 0.0705 | 0.0028 | 0.0000 |
| 0 | | 0.0874 | 0.0047 | 0.0000 | 0.0000 |

Table B-1. Exact Probabilities of Breaching
a Standard Minefield (continued)

| n = 6 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.2416 | 0.6869 | 0.9539 | 0.9978 |
| 2 | | 0.4389 | 0.2748 | 0.0454 | 0.0022 |
| 1 | | 0.2658 | 0.0366 | 0.0007 | 0.0000 |
| 0 | | 0.0536 | 0.0016 | 0.0000 | 0.0000 |

| n = 7 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.3136 | 0.7727 | 0.9767 | 0.9993 |
| 2 | | 0.4440 | 0.2080 | 0.0231 | 0.0007 |
| 1 | | 0.2095 | 0.0187 | 0.0002 | 0.0000 |
| 0 | | 0.0329 | 0.0006 | 0.0000 | 0.0000 |

| n = 8 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.3850 | 0.8368 | 0.9883 | 0.9998 |
| 2 | | 0.4327 | 0.1536 | 0.0116 | 0.0002 |
| 1 | | 0.1621 | 0.0094 | 0.0000 | 0.0000 |
| 0 | | 0.0202 | 0.0002 | 0.0000 | 0.0000 |

| n = 9 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.4537 | 0.8838 | 0.9942 | 0.9999 |
| 2 | | 0.4102 | 0.1115 | 0.0058 | 0.0001 |
| 1 | | 0.1237 | 0.0047 | 0.0000 | 0.0000 |
| 0 | | 0.0124 | 0.0001 | 0.0000 | 0.0000 |

| n = 10 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.5180 | 0.9176 | 0.9971 | 1.0000 |
| 2 | | 0.3810 | 0.0800 | 0.0029 | 0.0000 |
| 1 | | 0.0934 | 0.0023 | 0.0000 | 0.0000 |
| 0 | | 0.0076 | 0.0000 | 0.0000 | 0.0000 |

Table B-1. Exact Probabilities of Breaching
a Standard Minefield (continued)

| n = 11 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.5773 | 0.9418 | 0.9985 | 1.0000 |
| 2 | | 0.3481 | 0.0570 | 0.0015 | 0.0000 |
| 1 | | 0.0700 | 0.0011 | 0.0000 | 0.0000 |
| 0 | | 0.0047 | 0.0000 | 0.0000 | 0.0000 |

| n = 12 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.6311 | 0.9590 | 0.9993 | 1.0000 |
| 2 | | 0.3140 | 0.0404 | 0.0007 | 0.0000 |
| 1 | | 0.0521 | 0.0006 | 0.0000 | 0.0000 |
| 0 | | 0.0029 | 0.0000 | 0.0000 | 0.0000 |

| n = 13 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.6794 | 0.9712 | 0.9996 | 1.0000 |
| 2 | | 0.2803 | 0.0285 | 0.0004 | 0.0000 |
| 1 | | 0.0386 | 0.0003 | 0.0000 | 0.0000 |
| 0 | | 0.0018 | 0.0000 | 0.0000 | 0.0000 |

| n = 14 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.7223 | 0.9798 | 0.9998 | 1.0000 |
| 2 | | 0.2482 | 0.0201 | 0.0002 | 0.0000 |
| 1 | | 0.0284 | 0.0001 | 0.0000 | 0.0000 |
| 0 | | 0.0011 | 0.0000 | 0.0000 | 0.0000 |

| n = 15 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.7602 | 0.9858 | 0.9999 | 1.0000 |
| 2 | | 0.2183 | 0.0141 | 0.0001 | 0.0000 |
| 1 | | 0.0209 | 0.0001 | 0.0000 | 0.0000 |
| 0 | | 0.0007 | 0.0000 | 0.0000 | 0.0000 |

Table B-1. Exact Probabilities of Breaching
a Standard Minefield (continued)

| n = 16 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.7934 | 0.9901 | 1.0000 | 1.0000 |
| 2 | | 0.1909 | 0.0099 | 0.0000 | 0.0000 |
| 1 | | 0.0153 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0004 | 0.0000 | 0.0000 | 0.0000 |

| n = 17 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.8224 | 0.9930 | 1.0000 | 1.0000 |
| 2 | | 0.1662 | 0.0069 | 0.0000 | 0.0000 |
| 1 | | 0.0112 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0003 | 0.0000 | 0.0000 | 0.0000 |

| n = 18 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.8475 | 0.9951 | 1.0000 | 1.0000 |
| 2 | | 0.1441 | 0.0049 | 0.0000 | 0.0000 |
| 1 | | 0.0082 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0002 | 0.0000 | 0.0000 | 0.0000 |

| n = 19 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.8693 | 0.9966 | 1.0000 | 1.0000 |
| 2 | | 0.1246 | 0.0034 | 0.0000 | 0.0000 |
| 1 | | 0.0060 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0001 | 0.0000 | 0.0000 | 0.0000 |

| n = 20 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.8882 | 0.9976 | 1.0000 | 1.0000 |
| 2 | | 0.1074 | 0.0024 | 0.0000 | 0.0000 |
| 1 | | 0.0043 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0001 | 0.0000 | 0.0000 | 0.0000 |

Table B-1. Exact Probabilities of Breaching
a Standard Minefield (continued)

n = 21

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9044 | 0.9983 | 1.0000 | 1.0000 |
| 2 | 0.0924 | 0.0017 | 0.0000 | 0.0000 |
| 1 | 0.0031 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 22

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9183 | 0.9988 | 1.0000 | 1.0000 |
| 2 | 0.0794 | 0.0012 | 0.0000 | 0.0000 |
| 1 | 0.0023 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 23

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9303 | 0.9992 | 1.0000 | 1.0000 |
| 2 | 0.0681 | 0.0008 | 0.0000 | 0.0000 |
| 1 | 0.0017 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 24

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9405 | 0.9994 | 1.0000 | 1.0000 |
| 2 | 0.0583 | 0.0006 | 0.0000 | 0.0000 |
| 1 | 0.0012 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

n = 25

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9493 | 0.9996 | 1.0000 | 1.0000 |
| 2 | 0.0498 | 0.0004 | 0.0000 | 0.0000 |
| 1 | 0.0009 | 0.0000 | 0.0000 | 0.0000 |
| 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table B-1. Exact Probabilities of Breaching
a Standard Minefield (continued)

| n = 26 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9568 | 0.9997 | 1.0000 | 1.0000 |
| 2 | | 0.0426 | 0.0003 | 0.0000 | 0.0000 |
| 1 | | 0.0006 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| n = 27 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9632 | 0.9998 | 1.0000 | 1.0000 |
| 2 | | 0.0364 | 0.0002 | 0.0000 | 0.0000 |
| 1 | | 0.0005 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| n = 28 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9686 | 0.9999 | 1.0000 | 1.0000 |
| 2 | | 0.0310 | 0.0001 | 0.0000 | 0.0000 |
| 1 | | 0.0003 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| n = 29 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9733 | 0.9999 | 1.0000 | 1.0000 |
| 2 | | 0.0265 | 0.0001 | 0.0000 | 0.0000 |
| 1 | | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| n = 30 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9773 | 0.9999 | 1.0000 | 1.0000 |
| 2 | | 0.0225 | 0.0001 | 0.0000 | 0.0000 |
| 1 | | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| 0 | | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table B-2. Cumulative Probabilities of Breaching
a Standard Minefield

| n = 1 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.0034 | 0.0270 | 0.1250 | 0.3430 |
| 2 | | 0.0607 | 0.2160 | 0.5000 | 0.7840 |
| 1 | | 0.3859 | 0.6570 | 0.8750 | 0.9730 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 2 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.0214 | 0.1327 | 0.4219 | 0.7536 |
| 2 | | 0.1883 | 0.5150 | 0.8438 | 0.9772 |
| 1 | | 0.6229 | 0.8824 | 0.9844 | 0.9993 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 3 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.0575 | 0.2836 | 0.6699 | 0.9212 |
| 2 | | 0.3318 | 0.7278 | 0.9570 | 0.9979 |
| 1 | | 0.7684 | 0.9596 | 0.9980 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 4 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.1092 | 0.4388 | 0.8240 | 0.9759 |
| 2 | | 0.4670 | 0.8547 | 0.9888 | 0.9998 |
| 1 | | 0.8578 | 0.9862 | 0.9998 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 5 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.1722 | 0.5758 | 0.9091 | 0.9927 |
| 2 | | 0.5841 | 0.9248 | 0.9971 | 1.0000 |
| 1 | | 0.9126 | 0.9953 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table B-2. Cumulative Probabilities of Breaching
a Standard Minefield (continued)

| n = 6 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.2416 | 0.6869 | 0.9539 | 0.9978 |
| 2 | | 0.6806 | 0.9617 | 0.9993 | 1.0000 |
| 1 | | 0.9464 | 0.9984 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 7 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.3136 | 0.7727 | 0.9767 | 0.9993 |
| 2 | | 0.7576 | 0.9808 | 0.9998 | 1.0000 |
| 1 | | 0.9671 | 0.9994 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 8 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.3850 | 0.8368 | 0.9883 | 0.9998 |
| 2 | | 0.8177 | 0.9904 | 1.0000 | 1.0000 |
| 1 | | 0.9798 | 0.9998 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 9 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.4537 | 0.8838 | 0.9942 | 0.9999 |
| 2 | | 0.8639 | 0.9952 | 1.0000 | 1.0000 |
| 1 | | 0.9876 | 0.9999 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 10 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.5180 | 0.9176 | 0.9971 | 1.0000 |
| 2 | | 0.8990 | 0.9977 | 1.0000 | 1.0000 |
| 1 | | 0.9924 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table B-2. Cumulative Probabilities of Breaching
a Standard Minefield (continued)

| n = 11 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.5773 | 0.9418 | 0.9985 | 1.0000 |
| 2 | | 0.9254 | 0.9988 | 1.0000 | 1.0000 |
| 1 | | 0.9953 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 12 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.6311 | 0.9590 | 0.9993 | 1.0000 |
| 2 | | 0.9451 | 0.9994 | 1.0000 | 1.0000 |
| 1 | | 0.9971 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 13 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.6794 | 0.9712 | 0.9996 | 1.0000 |
| 2 | | 0.9597 | 0.9997 | 1.0000 | 1.0000 |
| 1 | | 0.9982 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 14 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.7223 | 0.9798 | 0.9998 | 1.0000 |
| 2 | | 0.9705 | 0.9999 | 1.0000 | 1.0000 |
| 1 | | 0.9989 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 15 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.7602 | 0.9858 | 0.9999 | 1.0000 |
| 2 | | 0.9784 | 0.9999 | 1.0000 | 1.0000 |
| 1 | | 0.9993 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table B-2. Cumulative Probabilities of Breaching
a Standard Minefield (continued)

| n = 16 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.7934 | 0.9901 | 1.0000 | 1.0000 |
| 2 | | 0.9843 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 0.9996 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 17 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.8224 | 0.9930 | 1.0000 | 1.0000 |
| 2 | | 0.9886 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 0.9997 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 18 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.8475 | 0.9951 | 1.0000 | 1.0000 |
| 2 | | 0.9917 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 0.9998 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 19 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.8693 | 0.9966 | 1.0000 | 1.0000 |
| 2 | | 0.9940 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 20 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.8882 | 0.9976 | 1.0000 | 1.0000 |
| 2 | | 0.9956 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 0.9999 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table B-2. Cumulative Probabilities of Breaching
a Standard Minefield (continued)

| n = 21 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9044 | 0.9983 | 1.0000 | 1.0000 |
| 2 | | 0.9968 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 22 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9183 | 0.9988 | 1.0000 | 1.0000 |
| 2 | | 0.9977 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 23 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9303 | 0.9992 | 1.0000 | 1.0000 |
| 2 | | 0.9983 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 24 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9405 | 0.9994 | 1.0000 | 1.0000 |
| 2 | | 0.9988 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

| n = 25 | | p(30-m) | | | |
|-------------------|--|---------|--------|--------|--------|
| Cleared Stretches | | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | | 0.9493 | 0.9996 | 1.0000 | 1.0000 |
| 2 | | 0.9991 | 1.0000 | 1.0000 | 1.0000 |
| 1 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table B-2. Cumulative Probabilities of Breaching
a Standard Minefield (continued)

n = 26

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9568 | 0.9997 | 1.0000 | 1.0000 |
| 2 | 0.9994 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 27

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9632 | 0.9998 | 1.0000 | 1.0000 |
| 2 | 0.9995 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 28

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9686 | 0.9999 | 1.0000 | 1.0000 |
| 2 | 0.9997 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 29

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9733 | 0.9999 | 1.0000 | 1.0000 |
| 2 | 0.9998 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

n = 30

| Cleared Stretches | p(30-m) | | | |
|----------------------|---------|--------|--------|--------|
| | 0.15 | 0.30 | 0.50 | 0.70 |
| 3 | 0.9773 | 0.9999 | 1.0000 | 1.0000 |
| 2 | 0.9998 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

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